A Path to N+3 Fuel-Flexible Combustors

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NASA Glenn Research Center
Green Aviation Technical Information Meeting
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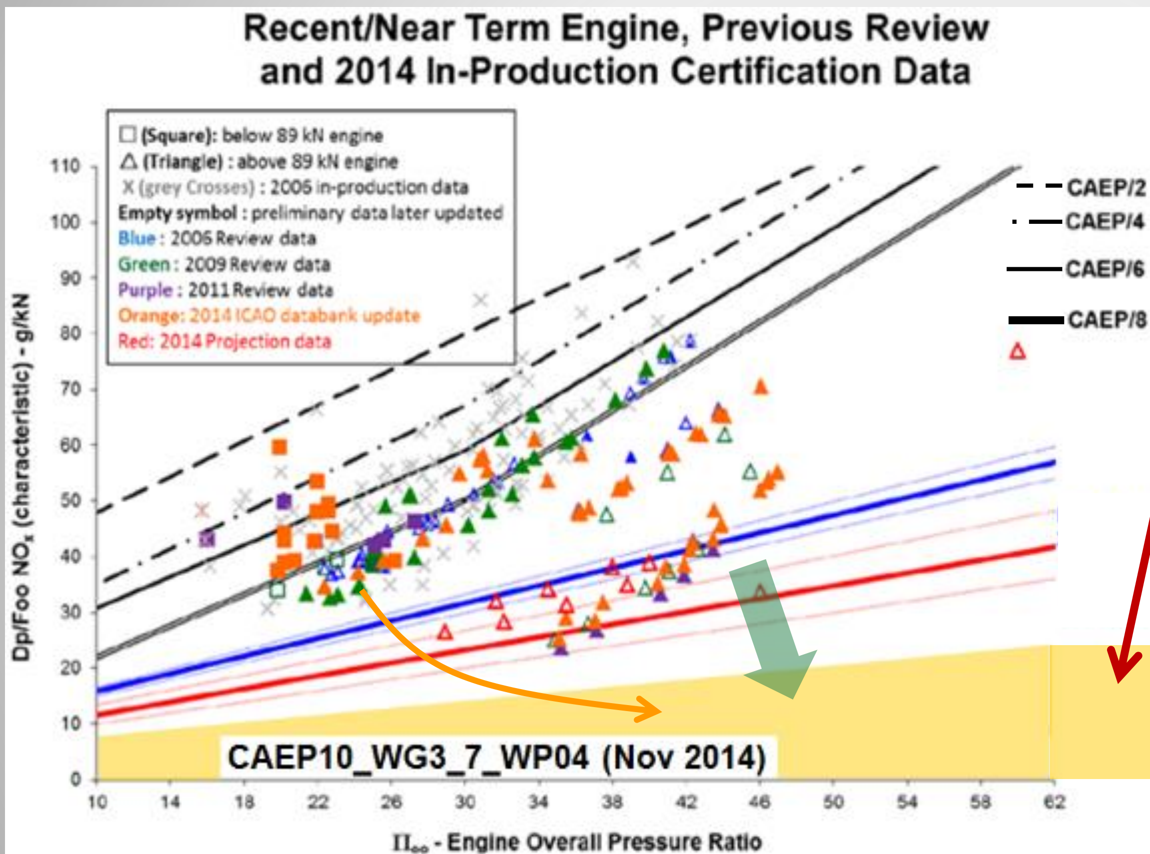
Technological Challenges for N+3 Small Core, Fuel- Flexible Combustors

Need to overcome trend for NOx to increase with OPR ↑

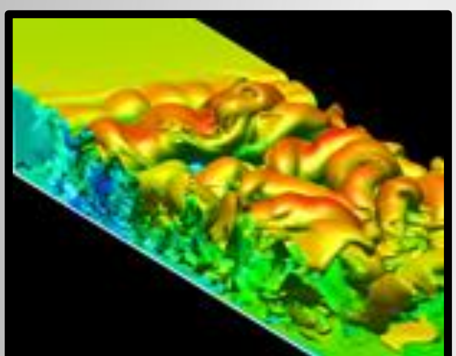


TECHNOLOGY BENEFITS*	N+3 (2025)
Noise (cum margin rel. to Stage 4)	-52 dB
LTO NOx Emissions (rel. to CAEP 6)	-80%
Cruise NOx Emissions (rel. to 2005 best in class)	-80%
Aircraft Fuel/Energy Consumption‡ (rel. to 2005 best in class)	-60%

Need to support high efficiency goal:
- **high OPR**
- **high BPR (small core)**

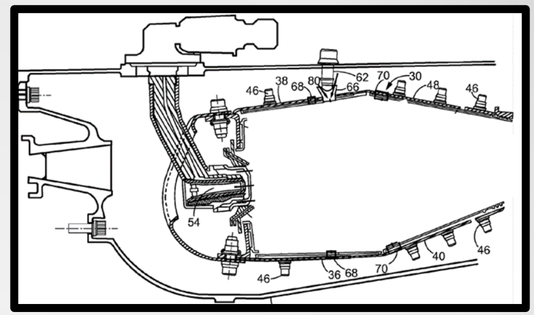
N+3 Small Core, Fuel - Flexible Combustor
Multiple Project's Support

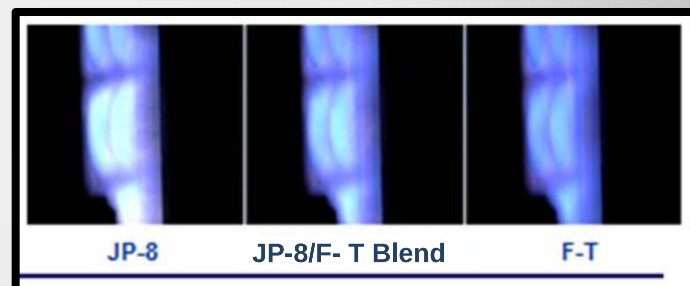
Transformative Tools and Technologies (TTT) Project



Objective : Develop and validate physics based combustion models, perform fundamental experiments and investigate new combustor technologies.
(TRL 2- TRL 5)

Advanced Air Transport Technology (AATT) Project

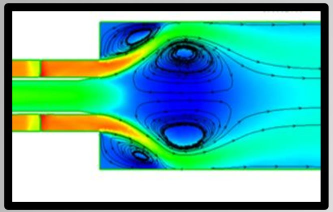


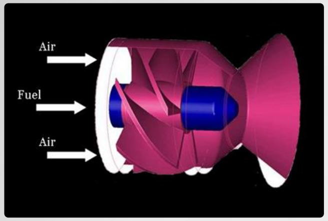


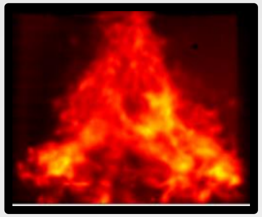
Objective : Reduce NOx emissions from small core , fuel-flexible combustors to 80% below the CAEP6 standard with minimal impacts on weight, noise, or component life.
(TRL 3 – TRL 6)

N+3 Small Core, Fuel - Flexible Combustor Multiple Project's Scope

Transformative Tools and Technologies (TTT) Project

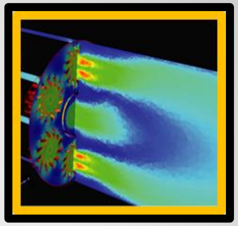






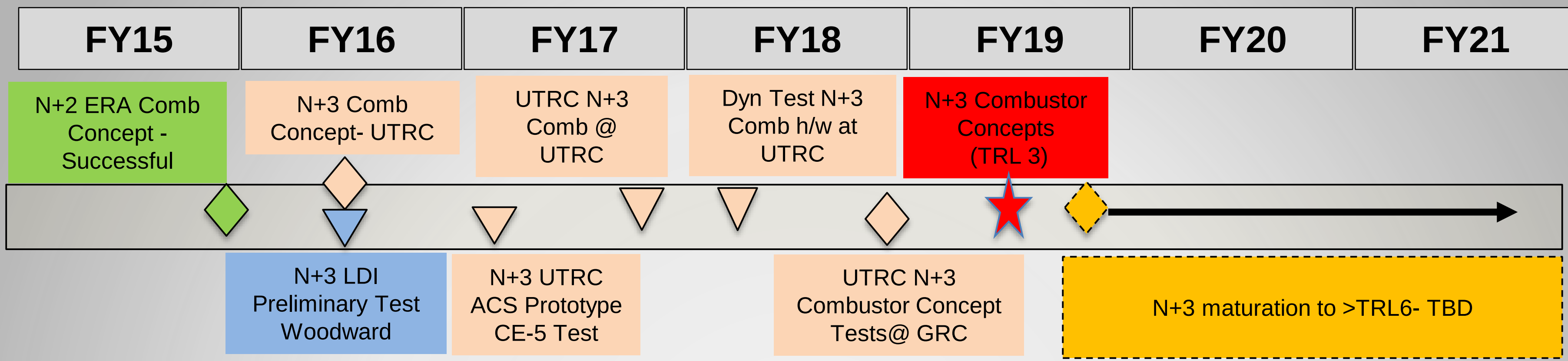
- **Develop/Validate Critical Computational Tools**
  - Physics-based CFD combustion models
  - Combustor-Turbine Interactions
  - Validation experiments
- **Develop/Test Critical Combustion Technologies**
  - Lean Direction Injection (LDI)
  - Staging Technologies
  - Combustion Dynamics Mitigation/Control
- **Explore/Evaluate Innovative Combustion Technologies/Concepts**
  - Pressure Gain Combustion Concepts

Advanced Air Transport Technology (AATT) Project



- **Fuel-Flexible Combustion**
  - Small Core Injection
  - Combustor Stability
  - Durability
  - Performance
- **Alternative fuel performance**
  - Thermal stability
  - Emissions
  - Lean blowout / ignition
  - Auto-Ignition / Flashback
  - Low aromatic effects
- **Particulate Matter Emissions**
  - PM emissions at ground and cruise altitudes extracted from combustor only

Technical Challenge 4.1
Low NOx, Fuel-Flex Combustor CAEP/6 -80%, TRL 3



AATT: Fuel-Flexible Combustor

- Explore/develop combustor concepts through flame tube tests
- Evaluate combustor dynamics & staging characteristics for N+3 high power-density operations
- Apply combustor system dynamics mitigation & active control technologies from TTT
- Evaluate impacts of alternative-fuels and blends on combustion and fuel systems in laboratory

TTT (TAC)

- High temperature CMC liners
- High-pressure spray validation data
- LDI fundamentals
- Closed-loop active combustor control strategy
- Combustion flow physics, fuel composition effects, and gaseous/particulate emissions
- Active combustion control

Other Research Theme Investments

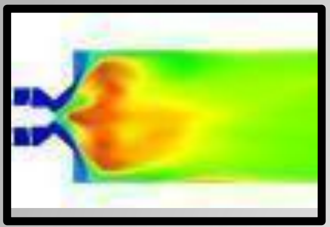
- *Particulate Matter Emissions*

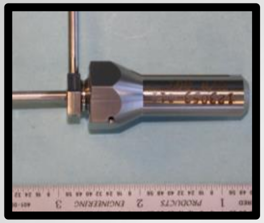
CST: High Altitude Emissions

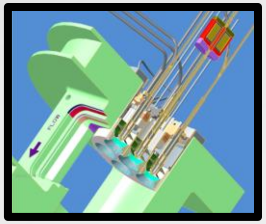
- Assess/adapt high-pressure comb designs from AATT for supersonic cruise conditions

N+3 Small Core, Fuel- Flexible Combustor In-House/ Partnership and Collaboration Efforts

Transformative Tools and Technologies (TTT) Project





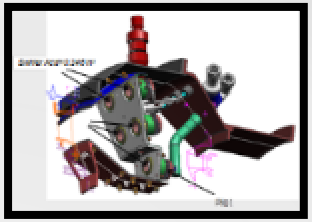


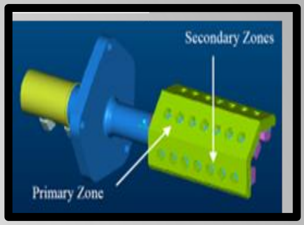
- **Develop reduced kinetics and turbulent combustion models sensitive to fuel composition and property changes**
  - Emerging Technical Challenge for TTT
  - TTT NRAs* supporting NJFCP
    - Standford & Uconn → reduced kinetics
    - Standford & Georgia Tech → turb/comb models
    - Operability (LBO, Ignition)
    - NOx and Soot Mechanisms

- **In- House Research**
  - Active Combustion control / Fuel Modulation with 7-point LDI
  - Staging/ LDI Pilot Strategies

- **National Jet Fuels Combustion Program**
  - Alternative fuel testing of 9-pt LDI in CE-5
  - OpenNCC simulations of AFRL Referee Rig

Advanced Air Transport Technology (AATT) Project





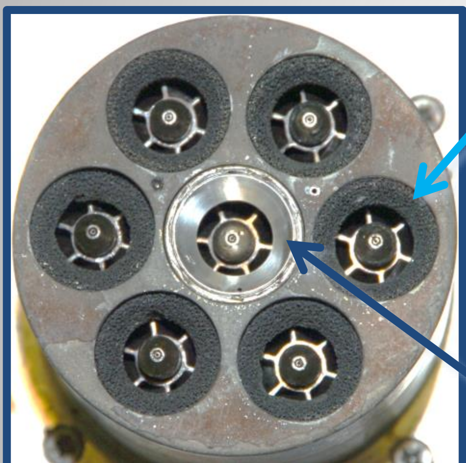
- **Fuel Flexible Combustor for High-OPR, Compact-Core N+3 Propulsion Engine**
  - UTRC NRA* Award
  - Space Act Agreement with Woodward FST
  - In-house 9-point LDI Injector
  - Systems Analysis Team (GRC) & Georgia Tech

- **Alternative Fuels/ Particulates**
  - National Jet Fuels Combustion Program (NJFCP) Alternative Fuels Combustion Tests
  - Space Act Agreement with FAA to support standardization of Particulate Measurement System

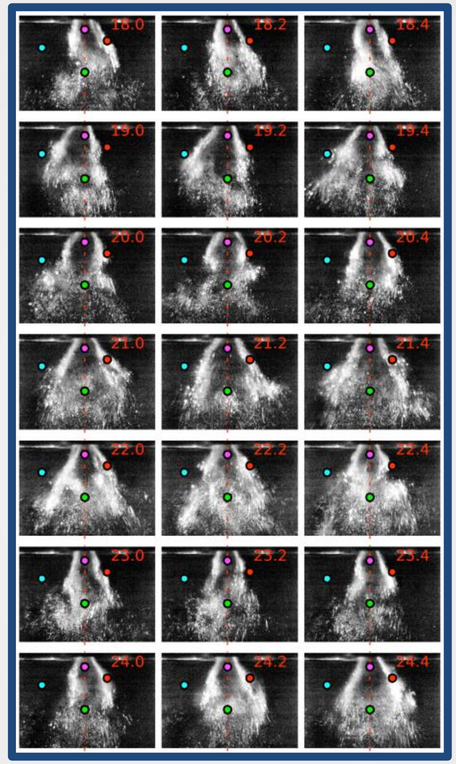
* NRA – NASA Research Announcement

CE-13C Combustion & Dynamics Facility

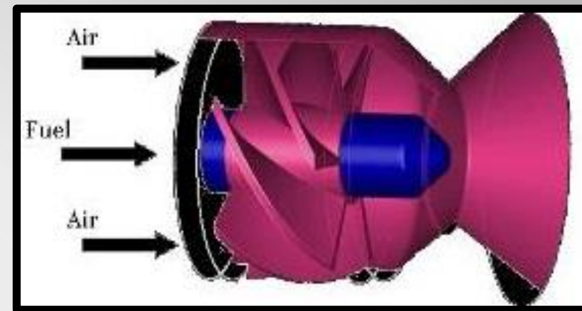
7-point, damping venturis

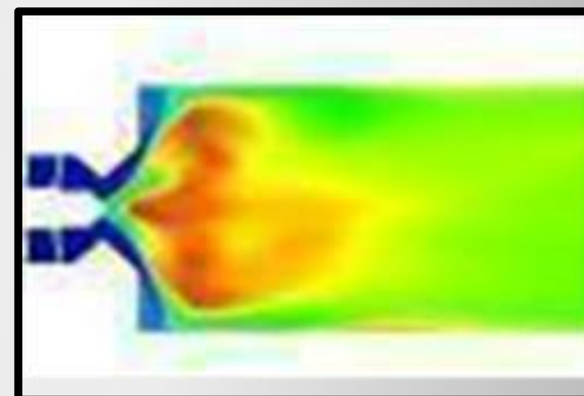


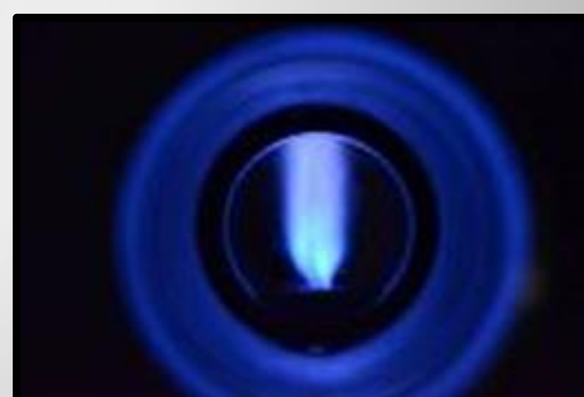
Mixing Studies



Single fuel/air mixer



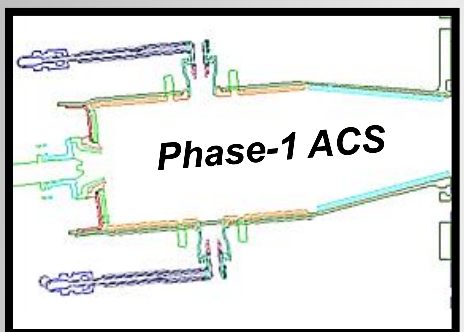


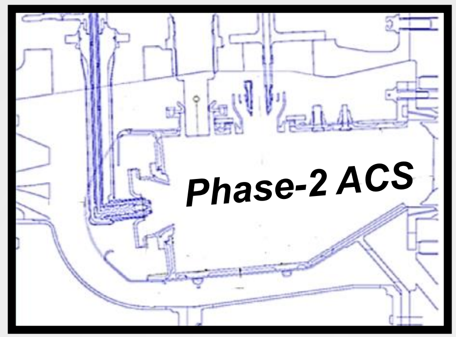


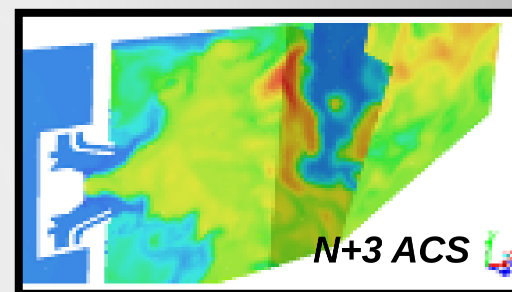
In-House Fundamental Combustion Research

NASA Research Announcement (NRA)
Small Core N+3 Combustor Development with UTRC/ P&W

Further developing P&W's ACS Combustor Concept to meet aggressive N+3 emissions goals, w/ scalability







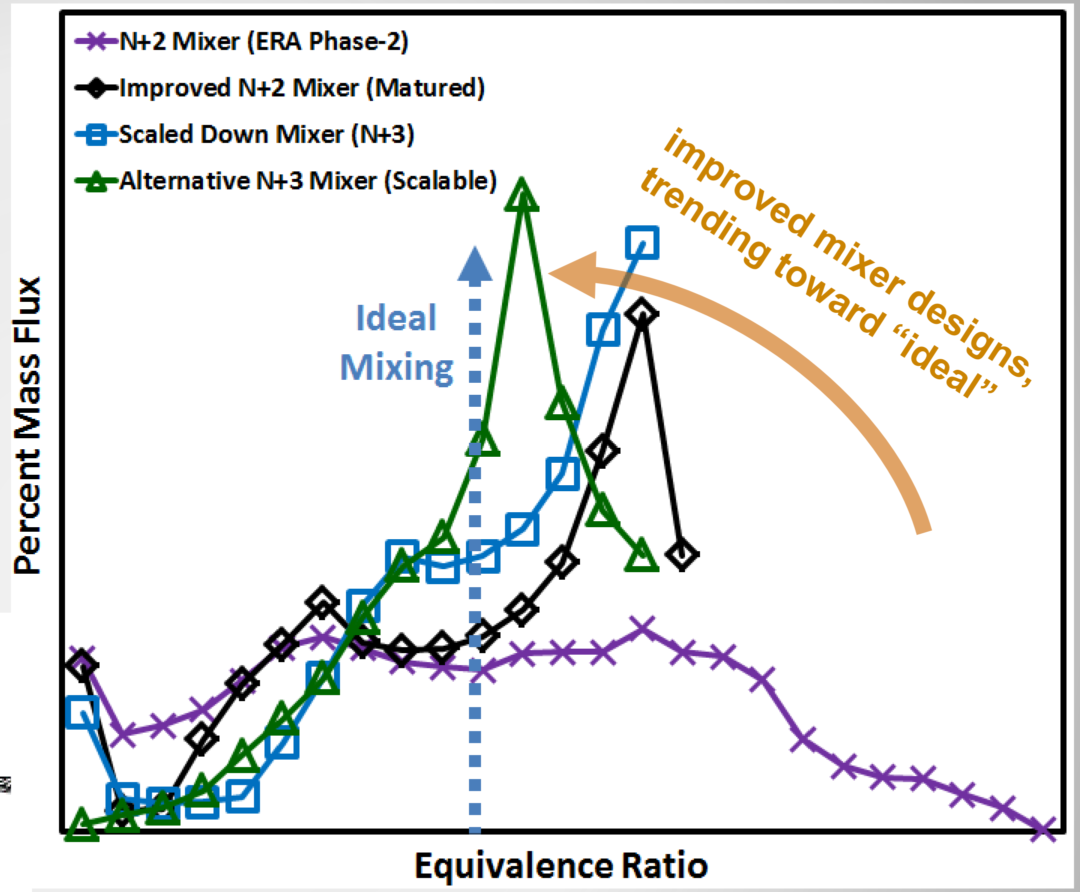
Combustor Feature	Phase-1 ACS Combustor	Phase-2 ACS Combustor (N+2)	N+3 ACS Combustor
Combustor Size & Config.	Unconstrained	Fits within existing GTF engine	Scale down for N+3
LTO NOx (%below CAEP6)	***–88%*** @ NASA ASCR	***–81%*** in full annular comb. tests	***>80%** margin*
Cruise NOx (%below 2005)	***–80-90%*** (EINOx basis)	***–68%*** (EINOx basis, vs. PW4098)	***>80%** margin*

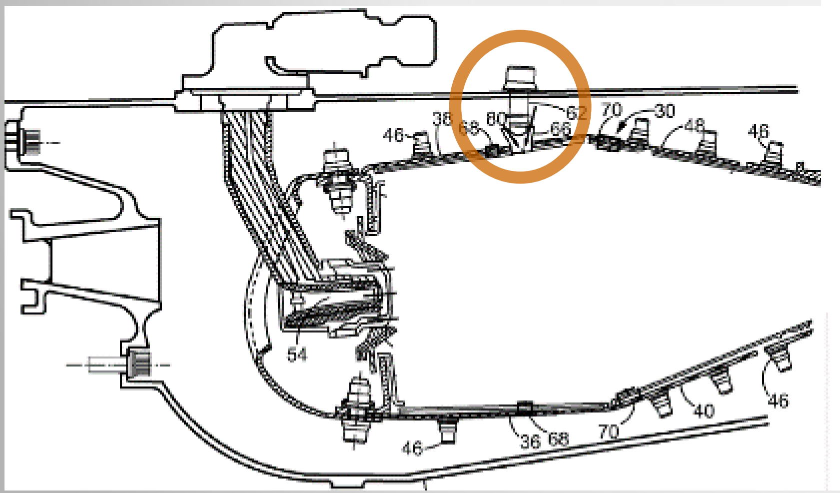
United Technologies Research Center

Fuel injectors / mixers critical to meeting N+3 emissions goals

Developing main mixers that:

- Meet auto-ignition and flashback criteria, for robust operation
- Approach "ideal" mixing for a wide range of operating conditions
- Are scalable to a range of engine core-sizes (N+2, N+3…)

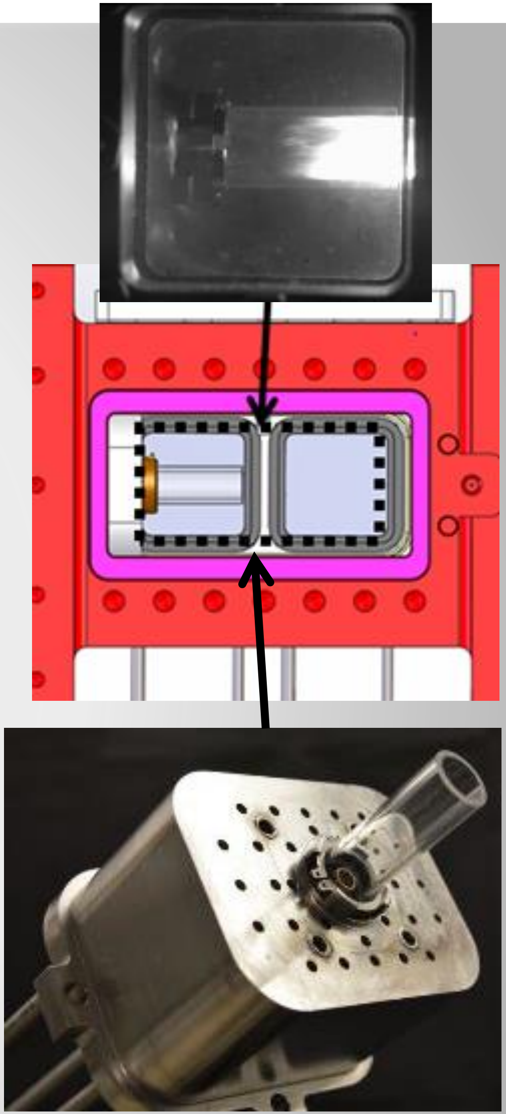




Alternative Fuel Investigations

Evaluating ACS technology for use with alternative fuels

	Fuel	POSF	ASCENT Designation	Selection Rationale	Performance Impact
1	Jet-A	10325	A-2	Baseline Properties	Baseline Performance
2	Gevo	11498	C-1	Low Cetane #	Longer ignition delay, loss of LBO margin
3	JP-5 (64v%)/Farnesane(36v%)	12341	C-3	High Viscosity/High Surface Tension	Droplet SMD Increase, slower fuel air mixing
4	iso-C10s (73v%)/trimethylbenzene(27v%)	12345	C-5	Flat distillation curve; Low Boiling Pt.	Faster vaporization, fuel-air mixing, pre-ignition
5	Rentech	7898	-	High Cetane #	Shorter ignition delay, pre-ignition, mixer length impact



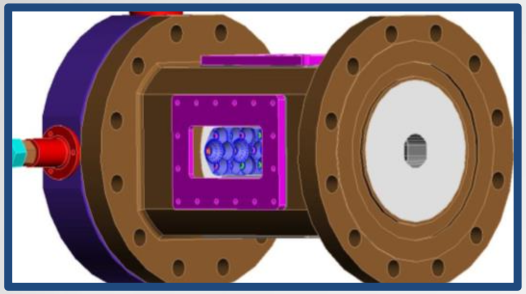
Evaluating auto-ignition for 4 alternative fuels & Jet-A:

- Fuels obtained from AFRL (NJFCP) & NASA
- Tests performed up to 800 psia, 1300 F inlet conditions
- Measuring auto-ignition location / time downstream of ACS mixer

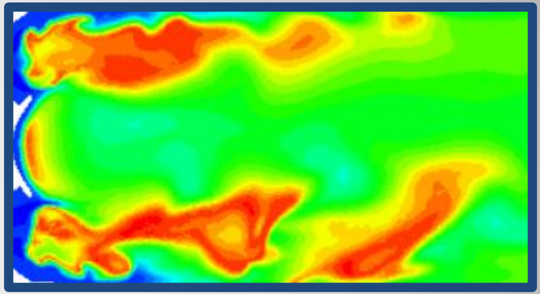
Space Act Agreement (SAA)
Woodward, FST

Objective: Develop a lean direct injection (LDI) concept for a small-core N+3 engine what will reduce NOx emissions by 80% wrt CAEP/6.

Small Core N+3 SV-LDI 3-cup hardware in flame-tube (TRL 3)

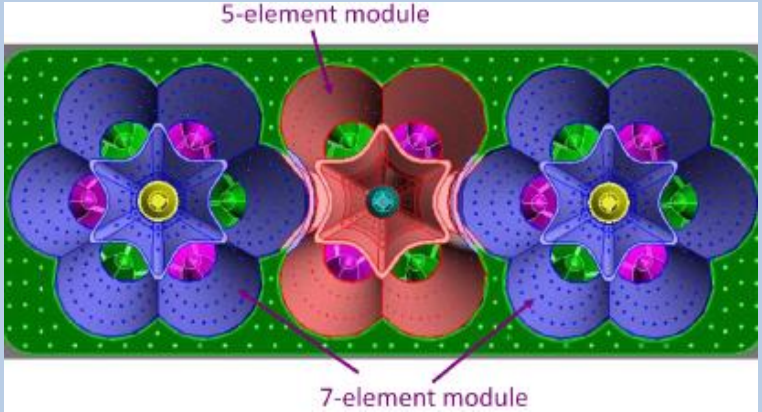


Recent CFD Flame Temperature Results



Small Core N+3 SV-LDI

N+3 Dome, Three Cups



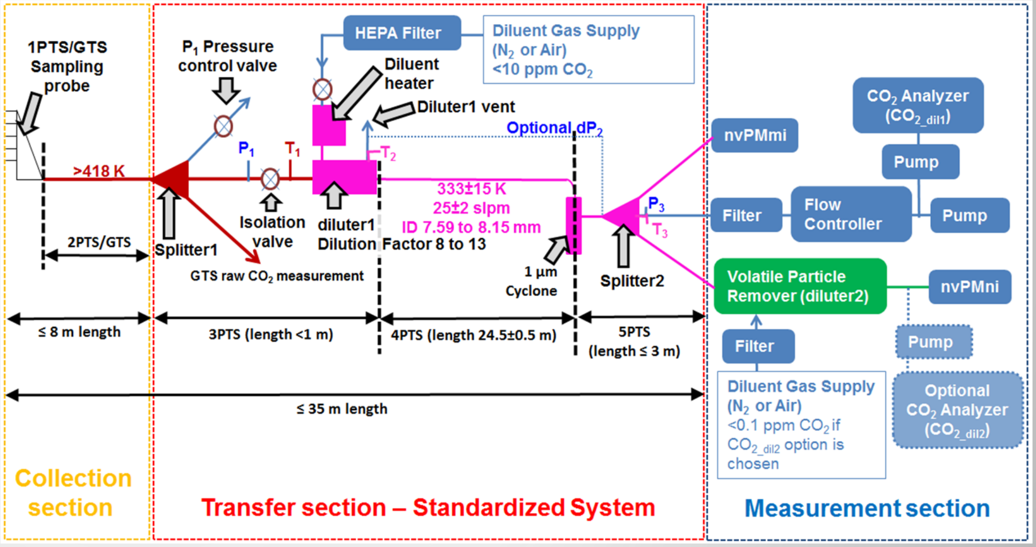
N+3 Fuel Stem

Space Act Agreement (SAA)
FAA- Aerosols and Particulate Measurements

Objective: Develop, validate and verify the operation of the FAA's AIR6241 Particulate Measurement system with NASA GRC's High pressure Flame- Tube Combustor Test Facility.

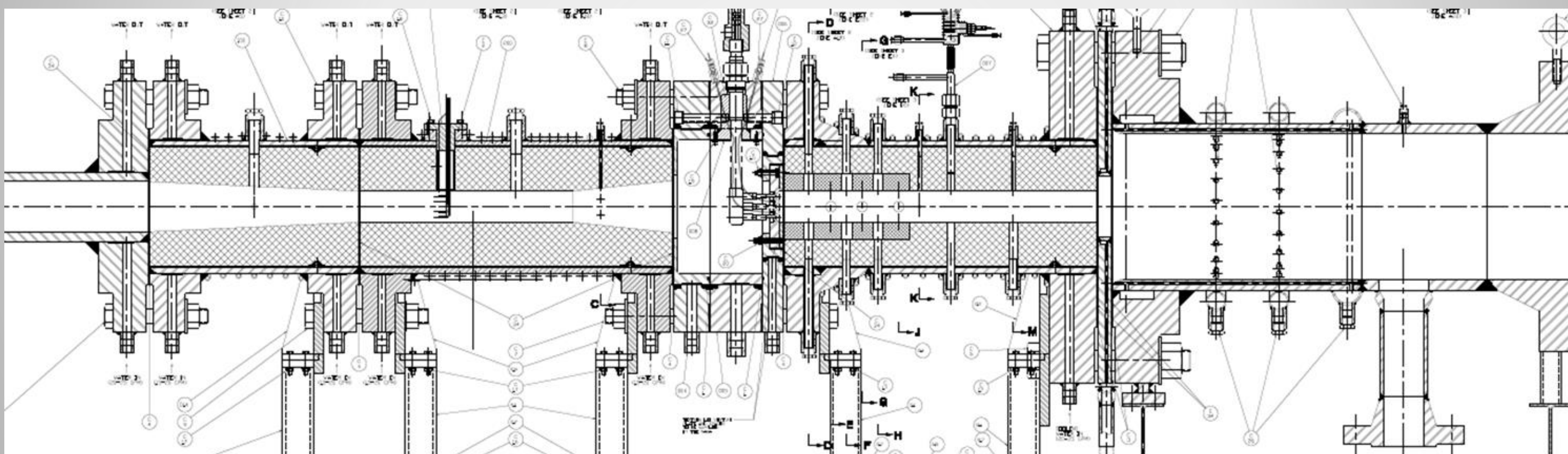
New Mobile Particulates Measurement System at GRC

Components of an AIR6241 System



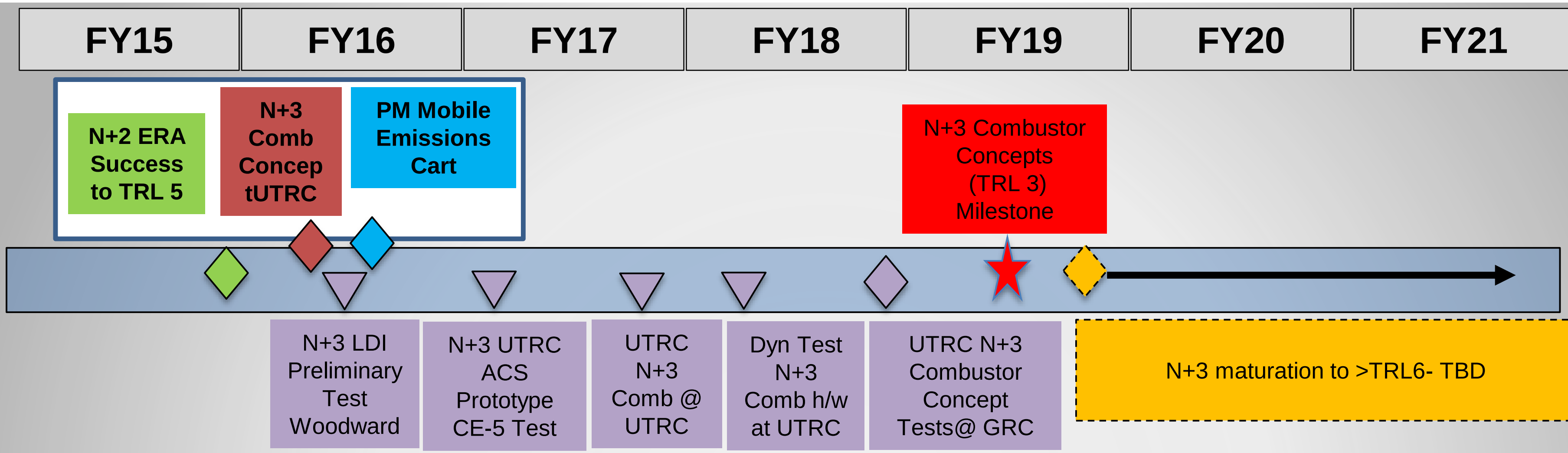
Advanced Subsonic Test Facility
New High Pressure Flame-Tube Design

	CE-5		ASCR
	Stand 1	Stand 2	Stand 2
Inlet Air Pressure Supply	450	450	1100
Combustor inlet Air Pressure P3 (PSI)	275	450	900
Inlet Airflow (PPS)	0.9 – 12	0.5 – 5	0.25 – 14
Combustor Inlet Air Temperature (F)	1200 (rated for 1350)	1100	1300
Fuel Supply Pressure (PSI)	900	900	2000



***Detailed Design ~75% Complete**
****Facility readiness dependent on funding, but could be as early as FY19**

Summary



- **Development of reduced kinetics/ comb models**
- **In- House Research for Active Combustion Control**
- **National Jet Fuels Combustion Program**
- **TRL 2-3**

- **N+3 Small Core, Fuel-Flexible Injector Tests**
- **Alternative Fuel Assessments**
- **Particulate Matter Characterization from High Pressure Combustor**
- **TRL 3**

- **N+3 Maturation to > TRL6**

NASA